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# MICROWAVE SATELLITE FORECASTING OF SNOWMELT RUNOFF

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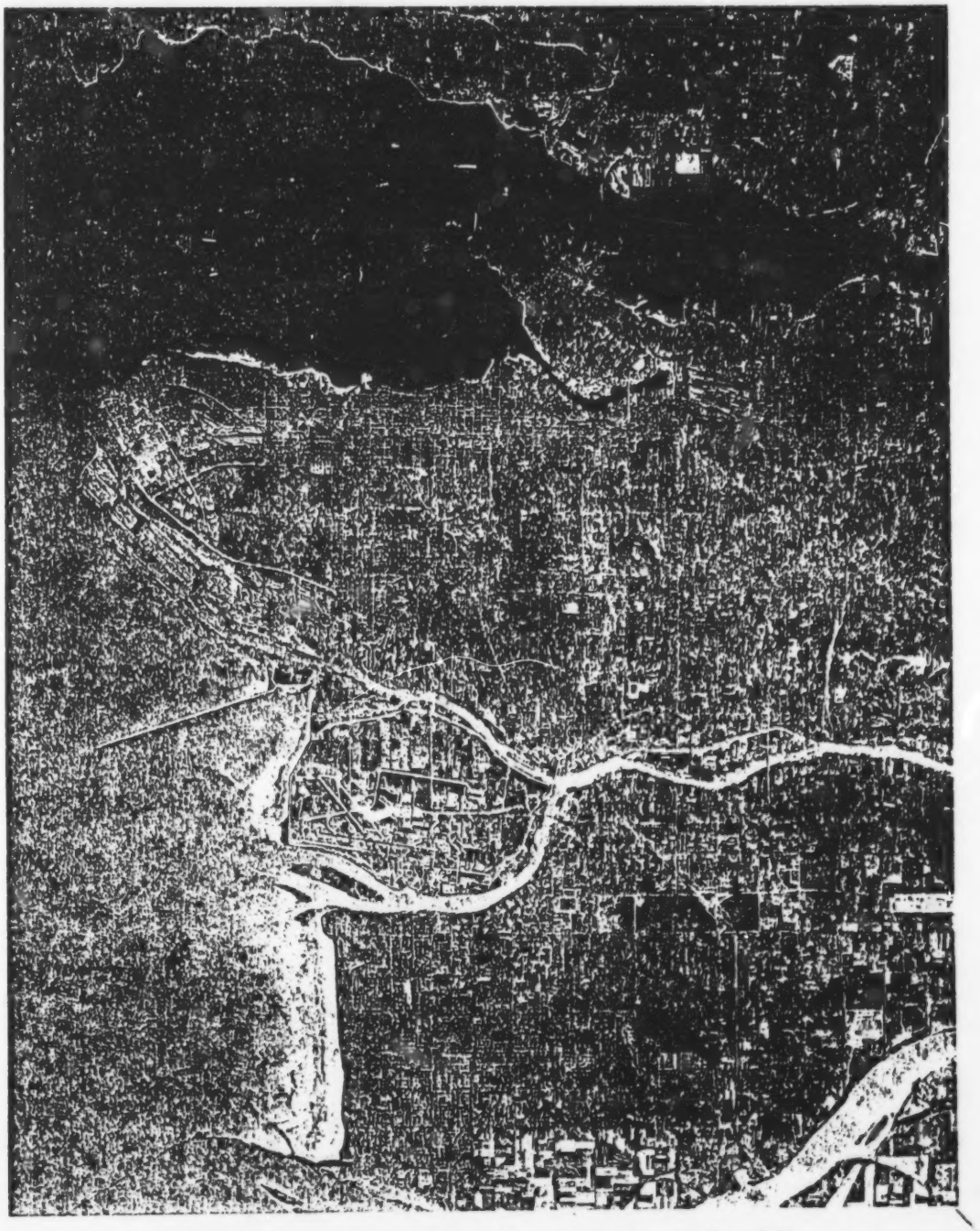
## An Economic Tool for the Nineties



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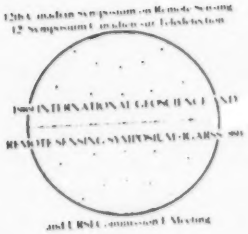

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# MICROWAVE SATELLITE FORECASTING OF SNOWMELT RUNOFF

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ABSTRACT
Microwave satellite observations of snowpacks can be used to estimate spring runoff from river basins. Correlations are prepared with Nimbus 5 ESMR data for fourteen different watersheds in the mountain, foothills, plateau and plains regions of Western Canada. The microwave method is shown to be as accurate as the conventional snow course method for forecasting runoff volumes. MICROWAVE, REMOTE SENSING, SNOWMELT

## 1. INTRODUCTION

Predictions of seasonal runoff volumes are used in engineering design and operational forecasts. The primary variable for estimating spring runoff is measured winter snow accumulation. Snowpack is conventionally estimated from snow courses or from accumulated snowfall. However, forecast accuracy is limited by the small number of network stations and frequency of surface observations.

Microwave satellites, on the other hand, can provide continuous coverage of snowpack, even in the presence of cloud cover. Since the first microwave satellite was launched in 1972, algorithms for monitoring snowpack have been developed from the observations (Kunzi et al 1982, Rango et al 1979, Goodison et al 1986, Wankiewicz, 1989a). This suggests that streamflow correlations can similarly be developed with satellite microwave observations. This paper will investigate the use of microwave brightness to forecast spring runoff, and compare results with those using conventional snow courses.

## 2. TARGET WATERSHEDS

The locations of fourteen target watersheds in Western Canada are shown in Figure 1. They exhibit a wide variety of relief and vegetation. Unregulated basins between 2500 and 25000 km2 were selected for analysis, if they contained less than 7% lake area on a 1:2000000 map. The watersheds are grouped into four physiographic regions: mountains, foothills, plateaux and plains. This was done according to the location of basin headwaters being in or near such regions shown in map 5-6 of Energy, Mines & Resources Canada (1973). Watershed characteristics are listed in Table 1. Basin slope is relief divided by farthest distance from the stream gauge; wetland area is taken from the wetlands map in Environment Canada (1981); vegetation is taken from the snow regionalization map of McKay & Findlay (1971). The annual runoff ratio is listed in the last column of Table 1. The runoff ratio is computed for each basin by dividing mean annual discharge published in Environment Canada (1987), by annual precipitation obtained from a map in Environment Canada (1978). Increasing runoff ration in the table are generally associated with increasing slope, and with decreasing wetland area.

## 3. MICROWAVE OBSERVATIONS

Microwave runoff correlations for individual watersheds are superimposed in Figure 2. Each point in a spring runoff event for a basin. The points appear to cluster according to the basin's physiographic region. Legends to identify these watersheds will be shown in Figures 5 to 8. The plateaux correlations would be located in the acute angle between foothills and plains, but have been omitted here for clarity.

Microwave brightness temperatures were obtained from Figures 3-15 to 3-17 of Parkinson et al (1987). These monthly maps summarize the Nimbus 5 ESMR observations taken at noon and midnight local time. The microwave data is for 19GHz nadir, with a resolution of about 30 km.

The Nimbus 5 observations cover most of the period 1973-76. Coincidentally, the target watersheds experienced record or near-record discharges in 1974 and/or 1976. Consequently, a wide range of flows had been observed, in spite of the comparatively short record.

Target watersheds were registered to the monthly maps to within 20km, and average brightness temperatures were computed for each winter. A fixed dry-snow observation period was established for each watershed that included only months with average air temperature normals below -2C, at the valley stations. The observation period was Jan-Feb for the mountain and/or BC basins; and was Jan-Mar for all other basins (but only Jan-Feb

are available for 1973).

4. SPRING RUNOFF CORRELATIONS

Conventional snow course correlations display a positive slope since runoff increases with snowpack. Figures 3 and 4 show March 1 snow course correlations for mountain and foothills basins respectively, prepared for the Nimbus 5 observation period.

By contrast, microwave correlations display a negative slope since snowpack reduces microwave brightness. Figures 5 and 6 display the mountain and foothills correlations on scales corresponding to those in Figures 3 and 4.

Spring runoff is taken to be the May-August runoff volume in mountain basins; and April-May runoff in foothills and plateaux. The flashy snowmelt runoff from the plains was computed by a detailed hydrograph separation.

The six basins with high runoff ratios, over 30% in Table 1, show correlations with microwave brightness alone. The four mountain basins in Figure 5 and the two correlated foothills basins in Figure 6, have runoff ratios in excess of 30%.

The five basins with low runoff ratios between 15 and 30%, done't have simple correlations. They display instead synchronous clockwise loops. This is shown by Beatton River in Figure 6 and by the plateaux basins in Figure 7 (except for West Road River in the BC Interior). Beatton, Notikewin and Chinchaga basins are actually adjacent to one another and share an extensive wetland that covers up to 60% of the basins (See Table 1). The loops suggest that antecedent moisture may be a significant secondary variable, but the co-ordination between the basins precludes a computation of multiple regression for that region.

The three basins with very low runoff ratios, 10% or less, are all located on the plains. Figure 8 shows their runoff to have a multiple linear correlation to both microwave brightness and the previous October runoff. The latter is an antecedent moisture index (AMI). Recent research shows that AMI can also be monitored by microwave satellite (Wilke & McFarland, 1986 and Wankiewicz, 1989b).

5. COMPARISON WITH SNOW COURSE CORRELATIONS

Correlation coefficients (R-values) are listed in Table 2 for both microwave and snow course methods. The F-test significance for non-random occurance is also listed for each R-value. For example, the microwave correlation for McLeod basin, has an R-value of 0.9, which for a sample of 4 points, has a non-random significance at the 90% level. Significance is even higher where regressions occur for a group of basins, such as the mountain watersheds.

Microwave forecasting of spring runoff appears to be as reliable as conventional forecasting methods. The two methods have comparable R-values and significance, as suggested by visual comparison of the diagrams.

6. ERROR ANALYSIS

The correlations appear to result from real runoff variations and not from systematic instrument errors or from spurious scatter. First, 1976 was a flood year for several correlated basins (e.g. Fraser, Columbia, Kootenay, Athabaska, Antler and Swan Rivers) while it was a low flow year for others (e.g. Simonette, McLeod and Iron Creek). An instrument calibration error, for example, cannot produce such contradictory effects. Second, ESMR observations have been successfully applied in other ways, e.g. in monitoring monthly streamflow on the plains by Wankiewicz (1989b), for April-October periods.

Regression scatter is produced by factors (i.e. antecedent moisture and runoff-period precipitation) that affect correlations in both microwave and conventional methods. The scatter about the microwave regression lines in figures 5 & 6 averages ±0.7K, with a maximum deviation of ± 2K.

7. CONCLUSIONS

A. Microwave correlations for spring runoff are regionalized by the characteristic runoff efficiency, roughness and vegetation cover of the watersheds.

B. Winter microwave emission is correlated to spring runoff for watersheds with an annual runoff to precipitation ratio over 30%. Microwave emission can be used in multiple correlations with an antecedent moisture index to forecast runoff on the plains.

C. Microwave correlations are as significant as snow course correlations for the same period of record, in mountain and foothills regions.

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TABLE 1. MICROWAVE TARGET WATERSHEDS

| WATERSHED | BASIN AREA km² | SLOPE $10^{-4}$ | WET AREA % | VEG. COVER | RUNOFF RATIO % |
|---|---|---|---|---|---|
| MOUNTAINS | | | | | |
| Fraser River | 18000 | 120 | 2 | SA forest | 109 |
| Columbia River | 9710 | 150 | 2 | SA forest | 86 |
| Kootenay River | 5390 | 210 | 2 | SA forest | 74 |
| Athabaska River | 9780 | 200 | 2 | SA forest | 78 |
| FOOTHILLS | | | | | |
| McLeod River | 9100 | 110 | 15 | Bor.forest | 48 |
| Simonette River | 5050 | 77 | 15 | Bor.forest | 34 |
| Beatton River | 15600 | 74 | 40 | Bor.forest | 22 |
| PLATEAUX | | | | | |
| Chinchaga River | 10400 | 34 | 60 | Bor.forest | 21 |
| Notikewin River | 4680 | 54 | 15 | Bor.forest | 22 |
| Birch River | 10000 | 56 | 60 | Bor.forest | 25 |
| West Road River | 12400 | 110 | 2 | Mon.forest | 19 |
| PLAINS | | | | | |
| Iron Creek | 3500 | 24 | 15 | Grain crops | 2 |
| Antler River | 3210 | 24 | 40 | Grain crops | 0.7 |
| Swan River | 4230 | 50 | 25 | for.& crops | 10 |

ABBREVIATIONS FOR VEGETATION REGIONS:
SA= SubAlpine; Bor.=Boreal; Mon.=Montane

TABLE 2. RUNOFF CORRELATION COEFFICIENTS

| WATERSHED | SNOW COURSES NO. | R | SIGNIF | MICROWAVE R | SIGNIF |
|---|---|---|---|---|---|
| MOUNTAINS | | | | | |
| Fraser River | 8 | 0.57 | NONE | 0.73 | POOR |
| Columbia River | 6 | 0.91 | V.G. | 0.81 | GOOD |
| Kootenay River | 9 | 0.90 | V.G. | 0.85 | GOOD |
| Athabaska River | 3 | 0.94 | V.G. | 0.87 | GOOD |
| FOOTHILLS | | | | | |
| McLeod River | 4 | 0.83 | GOOD | 0.90 | V.G. |
| Simonette River | 1 | 0.93 | V.G. | 0.96 | HIGH |
| Beatton River | 5 | 0.50 | NONE | 0.12 | NONE |

F-TEST SIGNIFICANCE THRESHHOLDS
FOR R-VALUES (SAMPLE SIZE=4): <67%-NONE;
67%-POOR; 80%-GOOD; 90%-V.G.; 95%-HIGH

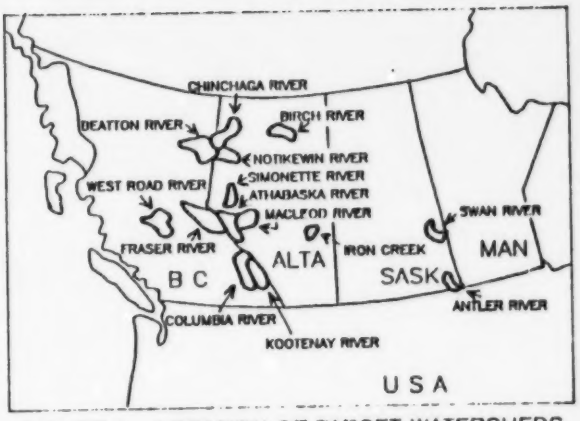


FIGURE 1. LOCATION OF TARGET WATERSHEDS

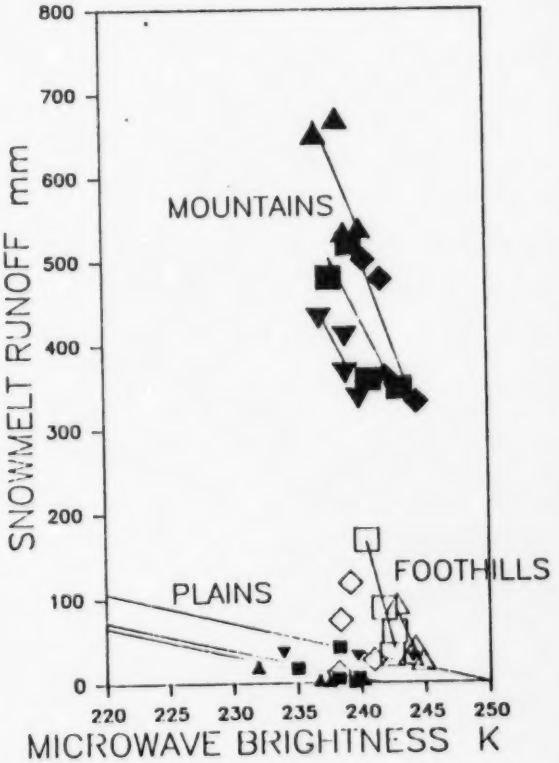


FIGURE 2. REGIONAL SNOWMELT CORRELATIONS WITH 19GHZ MICROWAVE OBSERVATIONS

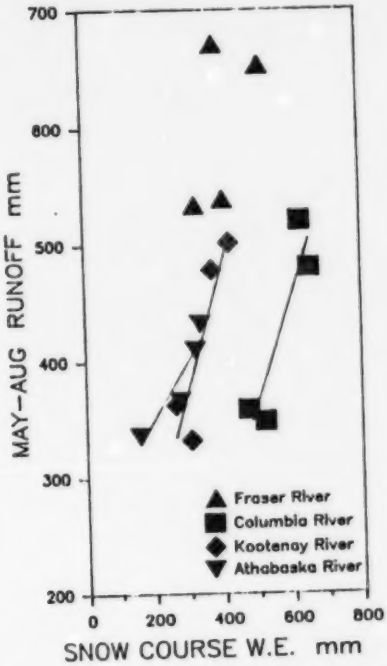


FIGURE 3. MOUNTAIN SNOWMELT RUNOFF CORRELATIONS WITH MAR 1 SNOW COURSE MEASUREMENTS

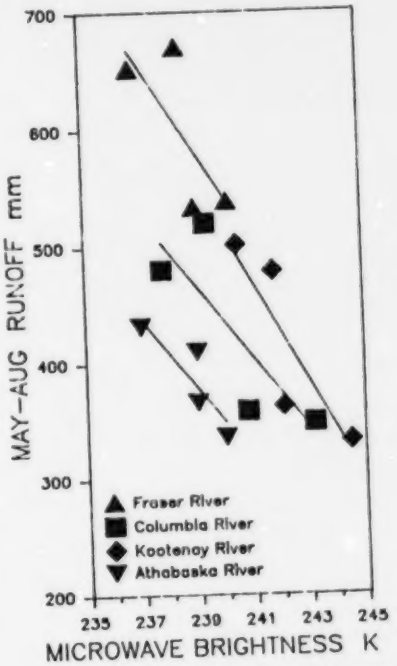


FIGURE 5. MOUNTAIN SNOWMELT RUNOFF CORRELATION WITH JAN –FEB MICROWAVE OBSERVATIONS

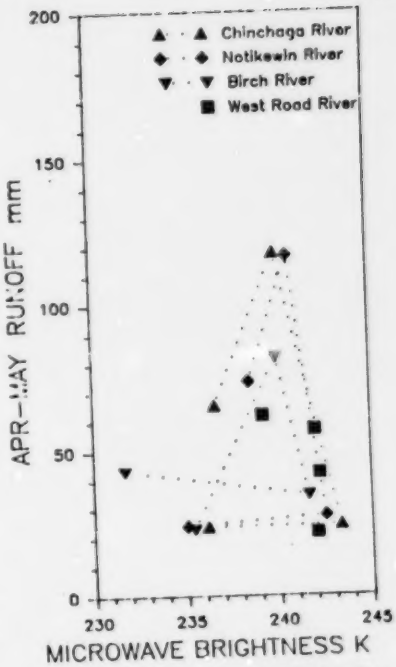


FIGURE 7. PLATEAUX SNOWMELT RUNOFF CORRELATIONS WITH JAN –MAR MICROWAVE OBSERVATIONS

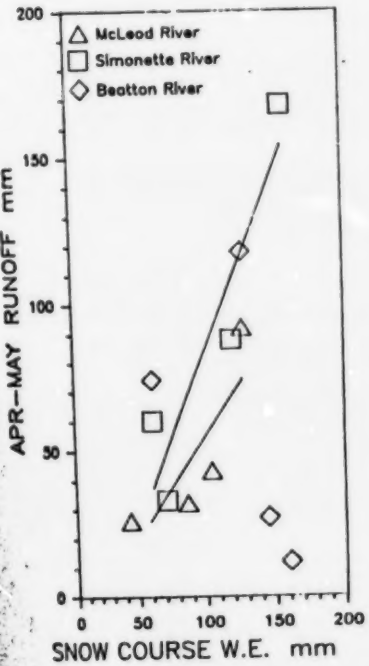


FIGURE 4. FOOTHILLS SNOWMELT RUNOFF CORRELATIONS WITH MAR 1 SNOW COURSE MEASUREMENTS

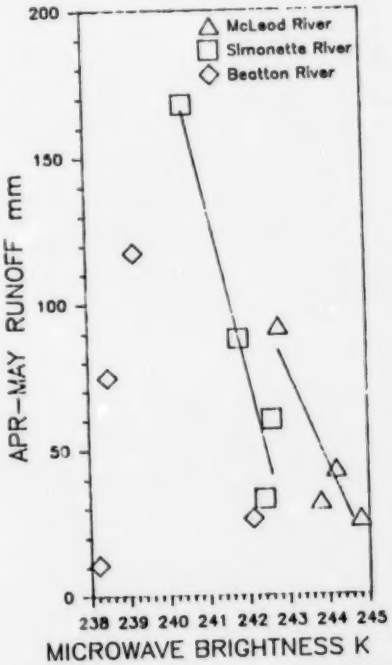


FIGURE 6. FOOTHILLS SNOWMELT RUNOFF CORRELATIONS WITH JAN –MAR MICROWAVE OBSERVATIONS

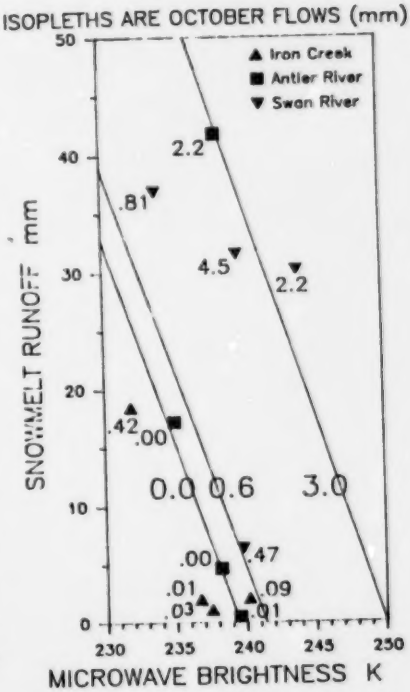


FIGURE 8. PLAINS SNOWMELT RUNOFF CORRELATIONS WITH JAN –MAR MICROWAVE OBSERVATIONS